

Model-based Testing with Graph Transformation Systems

Vincent de Bruijn

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Abstract

This report describes the setup of a research where the use of *Graph Transformation Systems* (GTS) in model-based testing is researched. The goal of the research is to create a system for automatic test generation on GTSs and to validate this system. A graph transformation tool, GROOVE, and a model-based testing tool, ATM, are used as part of the system. The system will be used in several case-studies and validated using the results of those case-studies. The potential benefits of this research are the advantages of GTSs in model-based testing.

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1 Introduction

Limited time and resources in software projects often make testing a neglected part of the software development process. However, testing is an important part of software development, because it decreases future maintenance costs. Therefore, the testing process should be as efficient as possible.

Test automation allows repeated testing during the development process. The advantage of this is that bugs are found early and can therefore be fixed. A widely used practice is maintaining a *test suite*, which is a collection of tests. However, when the creation of a test suite is done manually, this still leaves room for human error. Also, there is a trade-off between how much of the system is tested and how much time is spent on creating the test cases.

Creating an abstract representation or a *model* of the system is a way to tackle these problems. A model can be used to systematically generate tests for the system. This is referred to as *model-based testing*. This leads to a larger test suite in a shorter amount of time than if done manually. These models are created from the specifications from the software developer, end-user and/or owner. The process of collecting the specifications by the software developer into a model is still error-prone, due to imprecise, incomplete and ambiguous specifications. Therefore, the constructed model is potentially incorrect.

The stakeholders evaluate the constructed model to verify its correctness. However, the visual or textual representation of large models may become troublesome to understand, which obstructs this feedback process. Models that are often used are state machines, i.e. a collection of nodes representing the states of the system connected by transitions representing an action taken by the system. The overview is quickly lost with models of this type. The problem is therefore that errors in such models are not easily detected.

A formalism that among other things can describe software systems are Graph Transformation Systems (GTS). These systems express the system state and transitions by means of graphs. These graphs are a representation of the start state and the behavior of the system. The model is therefore a collection of graphs, each of a visual representation of one aspect of the system. This formalism may therefore provide a more intuitive approach to system modelling. Graph transformations and its potential benefits have been studied since the early '70s. The usage of this computational paradigm is best described by the following quote from Andries et al. [1]: "Graphs are well-known, well-understood, and frequently used means to represent system states, complex objects, diagrams, and networks, like flowcharts, entity-relationship diagrams, Petri nets, and many more. Rules have proved to be extremely useful for describing computations by local transformations: Arithmetic, syntactic, and deduction rules are well-known examples." An informative paper on graph transformations is written by Heckel et al.[5]. A quote from this paper: "Graphs and diagrams provide a simple and powerful approach to a variety of problems that are typical to computer science in general, and software engineering in particular."

1.1 Research setup

This report describes the setup of a research where the use of GTSs in model-based testing is researched. In the introduction the motivation is given for using this type of modelling technique. The goal is to create a system for automatic test generation on GTSs. This system is useful for software developers who require a testing tool that is easier to use with models that are easier to maintain. If the assumptions that GTSs provide a more intuitive modelling and testing process hold, this new testing approach will be less error-prone and will lead to less ambiguous specifications. The system design, once implemented and validated, provides a valuable contribution to the testing paradigm.

Tools that perform statespace exploration on GTSs and tools for automatic test generation already exist. Two of these tools will be used to perform these functions. The graph transformation tool GROOVE¹ will be used to model and explore the GTS. The testing tool developed by Axini² is used for the automatic test generation. This tool has no name, but will be referred to as Axini Test Manager (ATM).

The structure of this document is as follows: the research questions are listed in section 1.2. The model-based testing process is outlined in section 2. Sections 3 and 4 describe the relevant models. The tools used are introduced in section 5. The methods used in the research are in section 6. An overview of the related literature is made in section 7. Finally, conclusions are drawn in section 8. The planning for the research phase is in appendix A.

1.2 Research questions

The research questions are split into a design and validation component:

1. Design: How can automatic test generation be done using graph transformation systems? In particular, how can ATM be used together with GROOVE to achieve this?
2. Validation: What are the strengths and weaknesses of using graph transformation systems in model-based testing?

The result of the design question will be one system which incorporates ATM and GROOVE. This system will be referred to as GRATM. In order to answer the first research question sufficiently, GRATM should produce tests on the basis of a GTS and give correct verdicts whether the system contains errors or not.

The criteria used to assess the strengths and weaknesses are split into two parts: the objective and the subjective criteria. The objective criteria are the measurements that can be done on GRATM, such as speed and statespace size. The subjective criteria are related to how easy graph-transformation models are to use and maintain. The assessment of the latter criteria requires a human component. The criteria and methods for the assessment are elaborated in section 6.2.

GRATM will be validated using case-studies. These case-studies are done with existing specifications from systems tested by Axini. Each case-study will have a GTS and a symbolic model which describe the same system. The tool from the design part of the research and ATM are used for the automatic test generation on these models respectively. Both the model and the test process will then be compared as part of the validation. This includes the criteria mentioned in section 1.2. This is explained in more detail in section 6.2.

2 Model-based Testing

Model-based testing is a testing technique where a System Under Test (SUT) is tested for conformance with a model description of the system. The general setup for this process is depicted in Figure 1. The model is given to a test derivation component which generates test cases. These test cases are passed to a component that executes the test cases on the SUT. Tests are executed by providing input/stimuli to the SUT and monitoring the output/response. The test execution component evaluates the test cases, the stimuli and the responses and gives a 'pass' or a 'fail' verdict whether the SUT conforms to the specification or not.

¹<http://sourceforge.net/projects/groove/>

²<http://www.axini.nl/>

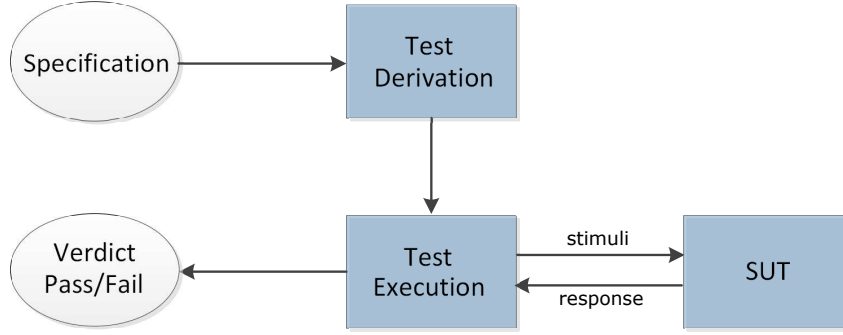


Figure 1: A general model-based testing setup

2.1 Input-Output Transition Systems

A formalism for describing system behavior is the Input-Output Transition System (IOTS). An example of such a transition system is shown in Figure 2a. This system allows an input of 20 or 50 cents and then outputs tea or coffee accordingly. The inputs are preceded by a question mark, the outputs are preceded by an exclamation mark. This system is a specification of a coffee machine. A test case can also be described by an IOTS. A test case for the coffee machine is given in Figure 2b. 50 cents is put into the machine, when the coffee output is observed from the system, the test passes, when the tea output is observed, the test fails.

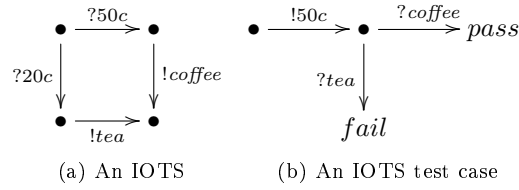


Figure 2: The specification of a coffee machine and a test case as an IOTS

3 Symbolic Transition Systems

Variations of state machines and transition systems have been widely used as the underlying model for test generation. Other tools use the structure of data types to generate test data. In this section, Symbolic Transition Systems (STS) are introduced which combine state transition systems with a data type oriented approach. These models do not suffer as quickly from the state-space explosion problem as Labelled Transition Systems do. They are used in practice in for instance the Axini tool.

3.1 Definition

The definition of an STS that follows is based on the definition given by Frantzen et al. [7]. The formalisms are then explained intuitively.

A Symbolic Transition System is a tuple $\langle L, l_0, \mathcal{V}, \iota, \mathcal{I}, \Lambda, \rightarrow \rangle$, where:

- L is a countable set of locations and l_0 is the initial location.
- \mathcal{V} is a countable set of location variables.

- ι is a set of mappings $\{v \mapsto x \mid v \in \mathcal{V}, x \in \mathcal{X}\}$ and \mathcal{X} is a collection of ground terms, representing the initialisation of the location variables.
- \mathcal{I} is a set of interaction variables, disjoint from \mathcal{V} .
- Λ is a finite set of gates. The unobservable gate is denoted $\tau(\tau \notin \Lambda)$; we write Λ_τ for $\Lambda \cup \{\tau\}$. The arity of a gate $\lambda \in \Lambda_\tau$, denoted $\text{arity}(\lambda)$, is a natural number. The parameters of a gate $\lambda \in \Lambda_\tau$, denoted $\text{param}(\lambda)$, is a tuple of length $\text{arity}(\lambda)$ of distinct interaction variables. We fix $\text{arity}(\tau) = 0$, i.e. the unobservable gate has no interaction variables.
- $\rightarrow \subseteq L \times \Lambda_\tau \times \mathcal{F}(\mathcal{V} \cup \mathcal{I} \cup \mathcal{X}) \times \{v \mapsto x \mid v \in \mathcal{V}, x \in \mathcal{G}(\mathcal{V} \cup \mathcal{I} \cup \mathcal{X})\} \times L$, where \mathcal{F} is the collection of boolean functions over a set of variables and ground terms and \mathcal{G} is the collection of mathematical functions over a set of variables and ground terms, is the switch relation. We write $l \xrightarrow{\lambda, \phi, \rho} l'$ instead of $(l, \lambda, \phi, \rho, l') \in \rightarrow$, where ϕ is referred to as the switch restriction (acting as a guard) and ρ as the update mapping. We require $\text{var}(\phi) \cup \text{var}(\rho) \subseteq \mathcal{V} \cup \text{param}(\lambda)$, where var is the collection of the variables used in the given guard or update mapping.

The location variables are *global* variables in the model, meaning the model keeps track of the values of these variables no matter in which location the system is in. They are specific to the model, meaning they do not keep track of memory values in the SUT. They have an initial value, which is given by the mapping in ι . Gates are often called the action or label of a switch relation. However, gates also have accompanying interaction variables, listed in the *param* tuple. The arity of a gate is therefore the number of parameters of the gate.

An STS has an underlying LTS, where the locations are collections of states and the switch relations are collections of transitions. A state in the LTS is a location plus evaluation of the location variables in the STS.

3.2 Example

In Figure 3 a simple board game is shown, where two players consecutively throw a die and move along four squares. The defining tuple of the STS is:

$$\langle \{throw, move\}, throw, \{T, P, D\}, \{T \mapsto 0, P \mapsto [0, 2], D \mapsto 0\}, \{d, p, l\}, \{throw?, move!\}, \\ \{throw \xrightarrow{throw?, 1 \leq d \leq 6, D \mapsto d} move, move \xrightarrow{move!, T = p \wedge l = (P[p] + D) \% 4, P[p] \mapsto l, T \mapsto p \% 2} throw\} \rangle$$

The variables T, P and D are the location variables symbolizing the player's turn, the positions of the players and the number of the die thrown respectively. The gate *move!* has *param* = $\langle p, l \rangle$ symbolizing which player moves to which location. The gate *throw?* has *param* = $\langle d \rangle$ symbolizing which number is thrown by the die. The switch relation with gate *throw?* has the restriction that the number of the die thrown is between one and six and the update sets the location variable D to the value of interaction variable d . The switch relations with gate *move!* have the restriction that it must be the turn of the player moving and that the new location of the player is the number of steps ahead as thrown by the die. The update mapping sets the location of the player to the correct value and passes the turn to the next player. In the figure the first row shows the gate, the second row shows the constraint and the last row shows the update of the variables.

4 Graph Transformation Systems

A Graph Transformation System is composed of a start graph and a set of transition rules. The start graph describes the system in its initial state. The transition rules apply changes to the graph, creating a new graph which describes the system in its new state.

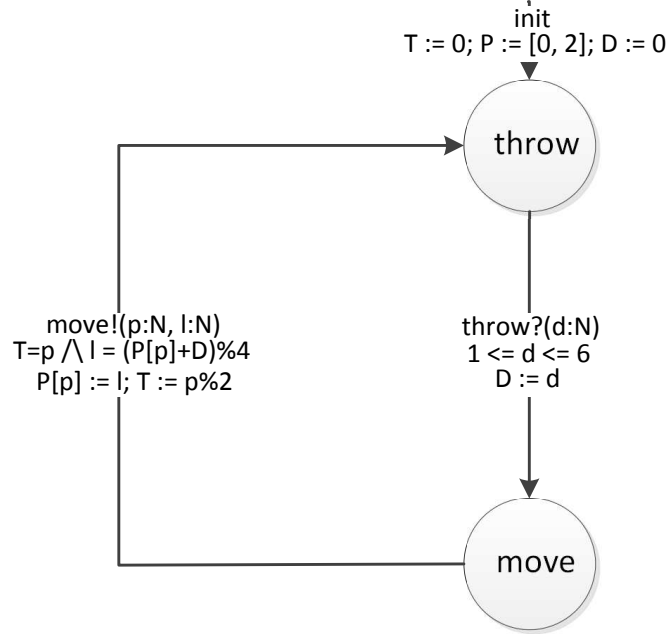


Figure 3: The STS of a board game example.

4.1 Definition

A Graph Transformation System is a tuple $\langle G, R \rangle$, where:

- G is a graph of the start state $\langle L, N, E \rangle$, where:
 - L is a set of labels
 - N is a set of nodes, where each $n \in N$ has a label $l \in L$
 - E is a set of edges, where each $e \in E$ has a label $l \in L$ and nodes $source, target \in N$
- R is a set of transformation rules (LHS, NAC, RHS) , where:
 - LHS is a graph representing the left-hand side of the rule
 - NAC is a set of graphs representing the negative application conditions
 - RHS is a graph representing the right-hand side of the rule

A graph H is a *subgraph* of G , denoted $H \subseteq G$, if the node and edge sets of H are subsets of the node and edge sets of G , where nodes are considered equal if their labels coincide and edges are considered the same if their labels and their source and target nodes coincide. A rule R is applicable on a graph G if $LHS \subseteq G \wedge \neg \exists c \in NAC. c \subseteq G$. The resulting graph after the rule application is determined by RHS of R . The nodes and edges in LHS are mapped to equal nodes and edges in RHS . All elements in LHS not part of the mapping are removed from G , all elements in RHS not part of the mapping are added to G and all elements part of the mapping are kept.

4.2 Example

The running example is displayed as a GROOVE GTS model in Figure 4. Figure 4a is the start graph of the system. The rules can be described as follows:

1. 4b: 'if a player has the turn and he has not thrown the die yet, he may do so.'

2. 4c: 'if a player has the turn and he has thrown the die and this number is larger than zero, he may move one place and then it is as if he has thrown one less.'
3. 4d: 'if a player has finished moving (number thrown is zero), the next player receives the turn.'

The *LHS*, *NAC* and *RHS* of each rule are displayed as one graph. The colored nodes and edges in the rules indicate to which part they belong:

1. normal line (black): This node or edge is part of both the *LHS* and *RHS*.
2. dotted line (red): This node or edge is part of the *NAC* only.
3. thick line (green): This node or edge is part of the *RHS* only.
4. dashed line (blue): This node or edge is part of the *LHS* only.

The *turn* flag on the *Player* node is a representation of a self-edge with label *turn*. The assignments on the *Die* node are representations of edges to integer nodes. The throws value assignment ($:=$) in the move rule represents an edge with the *throws* label to an integer node in the *LHS* and the same edge to another integer node in the *RHS*. In the next turn rule, the *turn* edge exists in the *LHS* as a self-edge of the left *Player* node and in the *RHS* as a self-edge of the right *Player* node. The *throws* edge from the left *Player* node to an integer node only exists in the *LHS*.

The graph is transformed after the rule is applied. This is the new state of the system and the rule is the transition from the old state (the graph as it was before the rule was applied) to the new state.

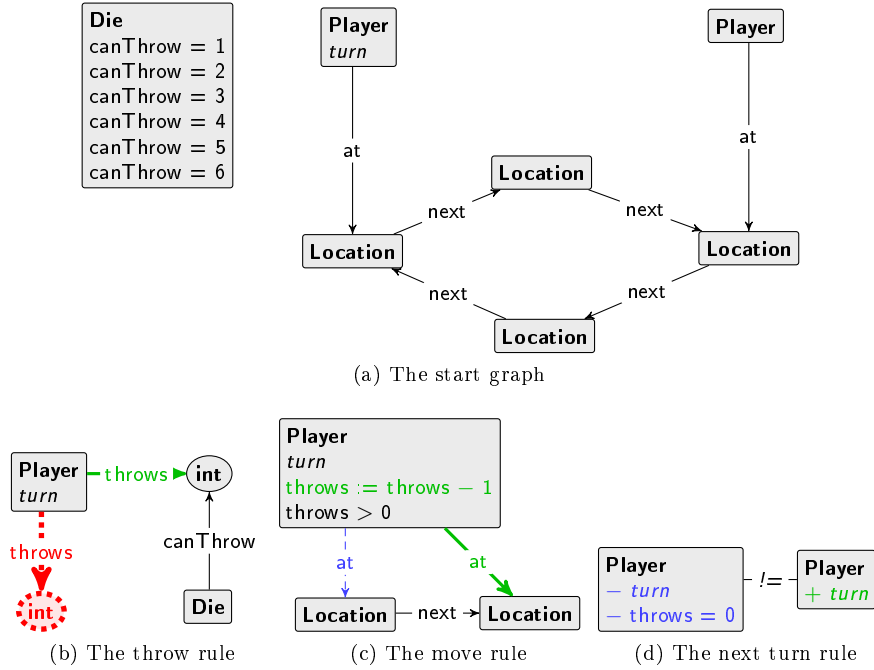


Figure 4: The GTS of the board game example in Figure 3

5 Tooling

5.1 Description Axini tool

The Axini tool is a web-based application, developed in the Ruby on Rails framework. The architecture is shown graphically in Figure 5. It has a similar structure to the model-based testing tool architecture in Figure 1. The main difference is that the testing in the Axini tool is done *on the fly*; no test cases are derived, instead a transition in the model is chosen and tested on the system directly.

An STS is given to a Model Interpreter component, which passes information on the current state and possible transitions to the Test Engine component, which devises the test cases. The stimuli given to the SUT are based on the labels of the switch relations of the STS. This component also includes the strategy component that decides on the specific data values to test. The Test Engine chooses a switch relation and the data values, thus a specific transition in the underlying LTS. This is given to the Test Execution component as an *abstract stimulus*. The term abstract is used here to indicate that the transition is specific to the model. It represents some computation steps taken in the SUT. For instance, the label 'connect' is an abstract stimulus of the actual setup of a TCP connection between two distributed components of the SUT. This 'translation' is done by the Test Execution component. When the SUT responds, the Test Execution component translates this response back to an abstract response. The Test Engine updates the Model Interpreter on which transition(s) were chosen and gives the pass or fail verdict based on the test case.

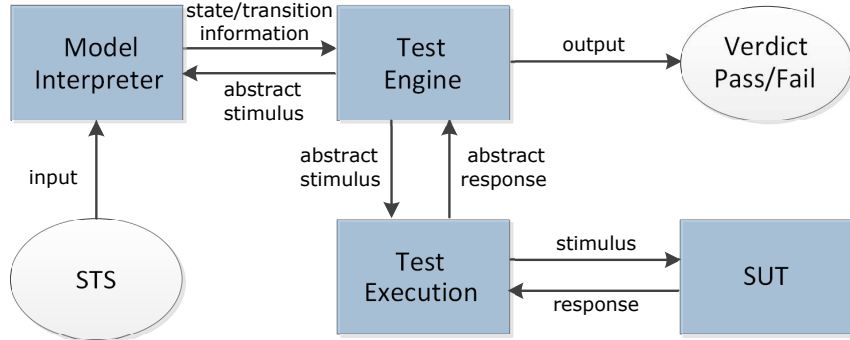


Figure 5: The Axini Tool

5.2 Description GROOVE

The architecture of the GROOVE tool is shown graphically in Figure 6. A Graph Transformation System is given as input to a Rule Applier component, which determines the possible rule matches. An Exploration Strategy can be started or the user can explore the states manually using the GUI. These components request the rule matches and give the chosen match as feedback. The Exploration Strategy can do an exhaustive search, leading to a Graph Transition System, which closely resembles an LTS, except the graph information is maintained in the state.

5.3 Comparison of the examples

The GTS of the running example in Figure 4 has a number of consecutive transitions when a player moves. This is different from the STS, which updates the location variable in one transition. The GTS can also model the location as a variable and update this variable in one transition. This

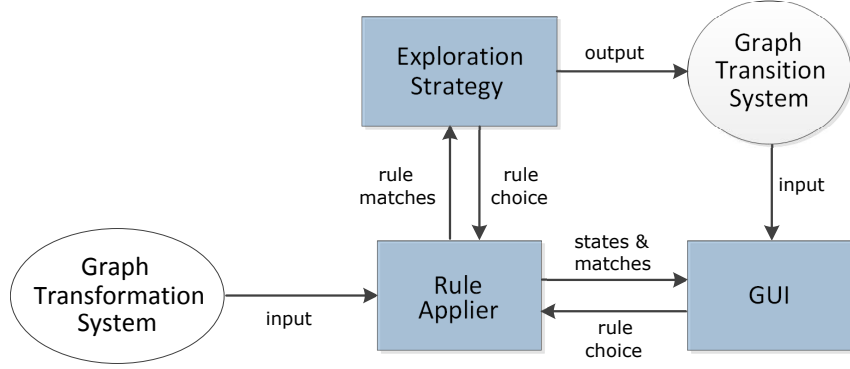


Figure 6: The GROOVE Tool

model is shown in Figure 7. The movement of the players as modelled in the GTS can also be modelled in an STS. Figure 8 shows this model.

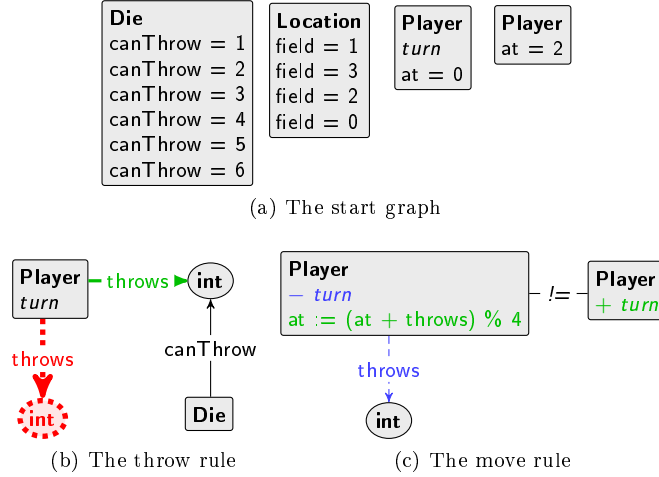


Figure 7: Another GTS model of the board game example

The new GTS loses many advantages by structuring it in this way: the overview of the board is gone, the rules are less visual and extending the locations in different directions is much harder. The rules do look more compact, there is even one rule less. However, when generating the Graph Transition Systems of both models with GROOVE a significant difference appears: the GTS from Figure 4 generates 32 states with 52 transitions, which can be seen visually in Figure 9, whereas the model from Figure 7 generates 112 states with 192 transitions (Figure 10). The reason is that the board is circular: to the first model, the players being at locations 1 and 3 is the same as them being at locations 2 and 4. However, this is not the same to the second model. This distinction results in a *symmetry reduction* in the first model and thus a smaller statespace than of the second model. In both models, another symmetry reduction takes place when the Players are at the same location.

The STS is also different than the one in Figure 3: now two switch relations are needed to move a player. The underlying LTS of the first model has 224 states and 384 transitions. This is calculated by taking all possibilities of the data values except for the die roll. This leads to 32 states ($4 \times 4 \times 2$). These 32 'throw' states each have 6 throw transitions to a 'move' state, thus there are 192 'move' states. The 'move' states only have one transition back to a 'throw' state. There are $6 \times 32 + 192 \times 1 = 384$ transitions. However, there is a possible bisimulation reduction. The specific value of D is not relevant anymore for the 'move' transitions in the LTS, as the

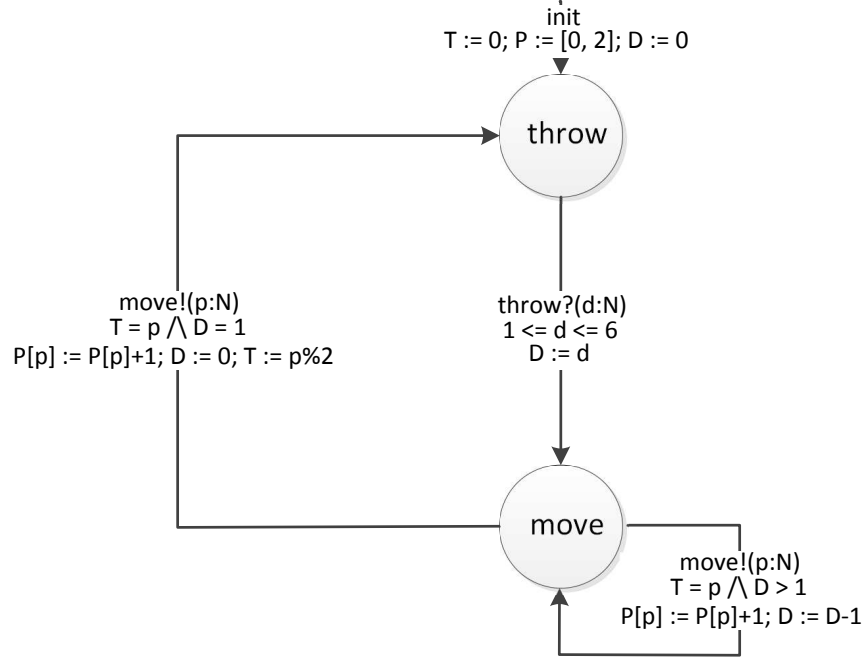


Figure 8: Another STS model of the board game example

constraint is already taken into account. Therefore the 'move' states that lead to the same 'throw' state can be grouped together. For each 'throw' state there is only one 'move' state, so this gives $32 \times 2 = 64$ states and $6 \times 32 + 32 \times 1 = 224$ transitions.

This reduction is not possible on the Graph Transition Systems, because state information is maintained in the states. The underlying LTS (derived from the Transition System by omitting the state information) does have this possible reduction. The symmetry reductions are possible on the STS, if more complex data values such as objects are allowed.

6 Research methods

6.1 Design

The specific method used to achieve the design goal is using GROOVE as a replacement of the symbolic model in the Axini tool. Figure 11 shows this graphically. The Rule Applier component now communicates with the Model Interpreter component. The communication runs through interfaces on both tools and through a socket over TCP, such that other tools like TorX are also able to communicate with the GROOVE component.

6.1.1 Problems

Already some problems with the implementation have been identified. They are listed in the following paragraph.

Modelling data types such as integers and strings in GROOVE is problematic; the range of possible values has to be given explicitly and cannot be infinite. For example, it would be impossible to extend the die of the running example such that it can throw any integer.

Repeated application of a rule in a GTS is sometimes a sign of one transition spread out across

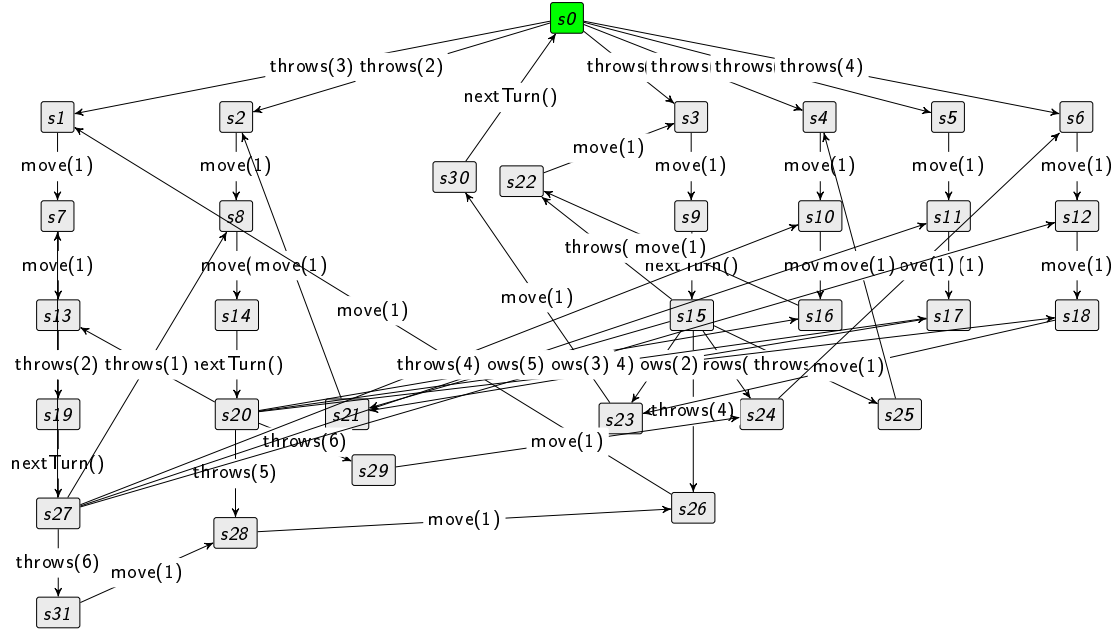


Figure 9: The Graph Transition System of the model in Figure 4

multiple transitions. In the case of the running example, this occurs with the player moving step by step.

The Axini tool annotates the locations it has been and the switch relations it has taken in the STS. The GTS does not have these locations and switch relations (it does have states and transitions), so it is hard to annotate these on the GROOVE side. This annotation is used for coverage statistics.

6.1.2 Coverage

State, transition, location and switch relation coverage are already implemented in the Axini tool. Location/switch relation coverage would also need to be implemented on the GROOVE tool. A representation of a location in GROOVE can be made by removing data values from a state graph. The applicable rules are a representation of the possible switch relations. Implementing this kind of 'graph/rule coverage' statistics is a possible field of research. An additional possible field of research is the implementation of data coverage statistics on the Axini Tool. This coverage statistic measures for each switch relation the representativeness of the data values used for all possible data values.

6.1.3 Design steps

The design steps will be done in increasing difficulty. In the next paragraph these steps are set out.

1. GROOVE will generate the entire LTS of the graph model and send it to the Axini tool for the test generation. The test engine in the Axini tool that accepts STSs is used, as this is the engine we want to modify. The LTS is also an STS, without variables, data values and constraints. The functionality of finding the underlying LTS of a GTS is already implemented in GROOVE. This will require the interface on both ends and the socket in between to be operational. The issue of limited data types should be solved at the end of this step.

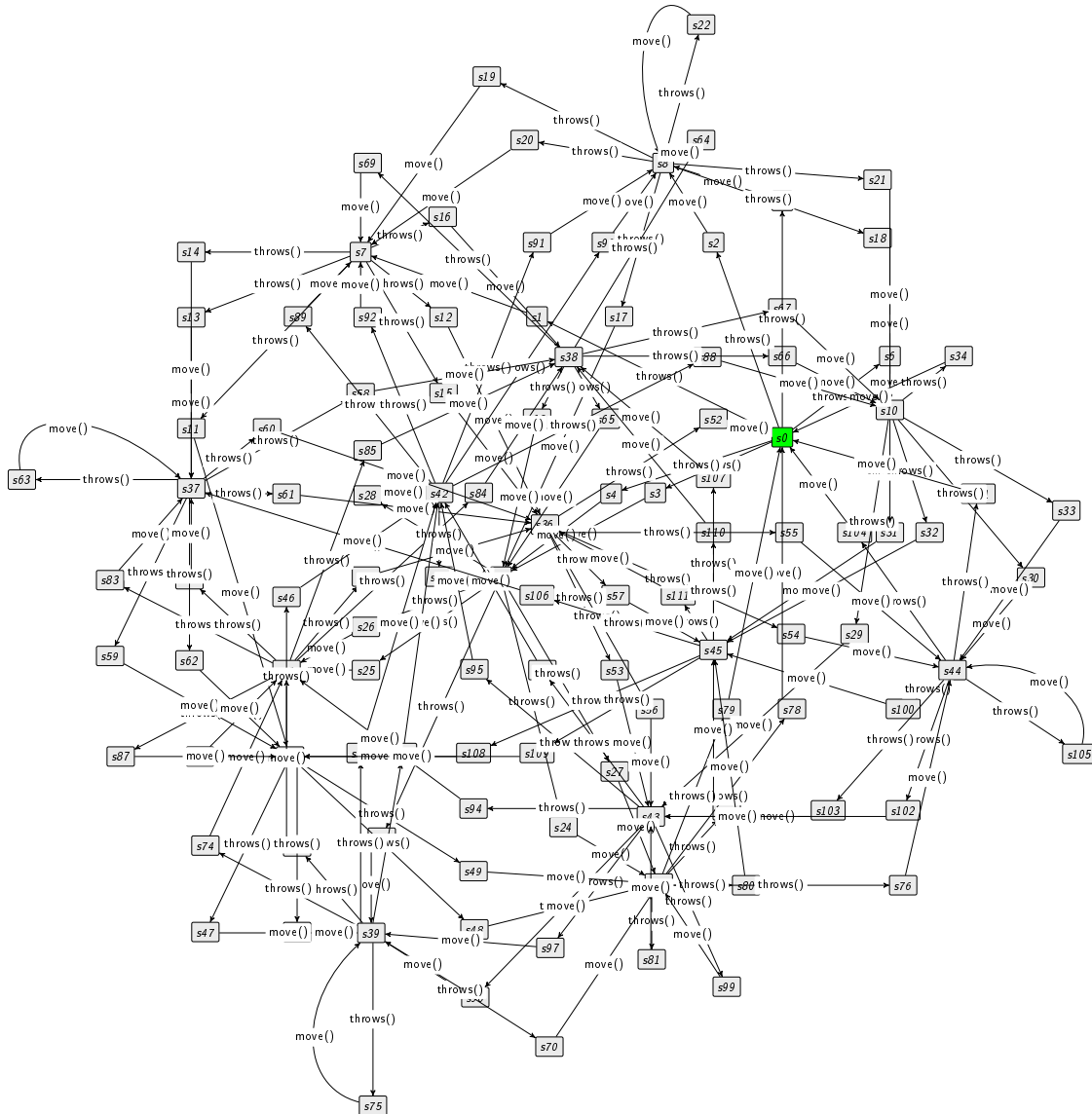


Figure 10: The Graph Transition System of the model in Figure 7

2. The interface on the GROOVE side will translate the GTS directly to an STS and transmit that instead of the LTS. This will require GTS-to-STs transformation rules. The issue that can be solved here is the grouping of transitions.
3. The final step is to implement a GTS engine on the Axini side and communicate on-the-fly as the statespace of the GTS is explored on the GROOVE side. The final issue of location annotation for coverage statistics should be solved at the end of this step.

6.2 Validation

The first step in validating the newly created tool is by testing a small model, namely the running example. A SUT is made for this board game and the Axini tool is used to test this game. Then, the GROOVE-Axini tool is used to test the game. The results should reveal no errors, fail verdicts

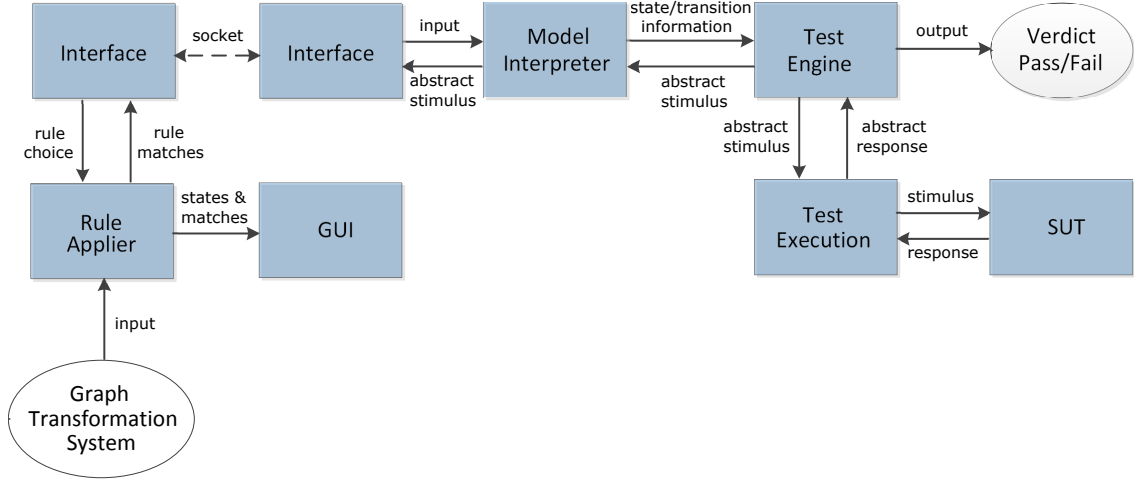


Figure 11: Replacing the symbolic model with GROOVE

or other differences in the output of both tools. An intentional error is then made in the SUT and the process is repeated. Still no errors or differences are expected, but both tools should find the error and give a fail verdict. Next, the assessment of the strengths and weaknesses of the resulting GROOVE-Axini tool is done by applying both tools to several case studies and comparing the results. The case studies are set out first and then the criteria for the comparison are given.

6.2.1 Case studies

One modelling technique might prove more practical for one kind of system, while the other modelling technique for another kind of system. Therefore, three case studies are planned. They are all real-life systems Axini has worked on:

- a self-scan register
- a navigation system
- a health-care system

The self-scan register is a machine that automates the purchase of products at a supermarket. A customer can put his products on a conveyer belt and the system automatically calculates the price of the products. Then the customer pays and gets a receipt. The navigation system is a GPS device with a route planner. It allows a user to enter a destination and the system plans the correct route accordingly from the location of the user. The health-care system is a medical device. This case study is not yet confirmed.

6.2.2 Objective criteria

As mentioned in section 1.2, the criteria are split in two parts. The objective criteria that can be compared are:

1. The verdicts
2. The number of bugs found
3. The coverage
4. The test cases generated per second

5. The size of the statespace

Same test cases should give same verdicts. When a verdict is different for the same test case in the GROOVE-Axini tool and the Axini tool, this might indicate an error. Another possibility is that one tool generates smarter test-cases and finds more bugs or reaches a higher coverage. The tools are also benchmarked on how fast they generate test-cases and on how much space they use.

6.2.3 Subjective criteria

This research will not include an extensive experiment with a statistical significant set of human actors. However, a group of experts in the field will be invited to a discussion at the end of the research period. This will include students and doctorates from the Formal Methods department of the University of Twente and employees from Axini. Preceding the discussion, the case studies and comparisons are presented. The discussion is meant for the participants to become acquainted with both modelling techniques and share ideas and thoughts. After the discussion, the participants are asked to work on one of the case studies. This work entails either:

1. Extending the model with a new feature
2. Finding a bug/error in the SUT/model

The following results are then noted and compared:

1. The time spent on the assignment
2. The correctness of the result
3. The feelings the participants had with the assignment (how difficult, how much fun, etc.)

With these results also the affiliation of the participants is taken into account: people from Axini and GROOVE are expected to do a better in their respective fields. Therefore, they will also be able to compare both modelling processes when working with the other tool than the one they are already familiar with.

The results will give insight in the understandability, maintainability and extendibility of both modelling processes. The results are compiled and presented in the final thesis.

7 Related work

7.1 Model-based testing

Formal testing theory was introduced by De Nicola et al.[8]. This testing theory was first used in algorithms for automatic test generation by Brinksma[2]. The specification language LOTOS was used in this research as a defining notation for transition systems. Tretmans gives a formal approach to protocol conformance testing (whether a protocol conforms to its specifications) in [11]. A useful transition system for model-based testing is the input-output transition system by Tretmans[12], assuming that implementations communicate with their environment via inputs and outputs. A good overview of model-based testing theory and past research is given in "Model-Based Testing of Reactive Systems" [?].

A tool for the automatic synthesis of test cases for nondeterministic systems is TGV[6]. Another tool, TorX, integrates automatic test generation, test execution, and test analysis in an on-the-fly manner[10]. A version of this tool written in Java under continuous development is JTorX [?].

7.2 Symbolic

Symbolic test generation is introduced by Rusu et al. [9], using Input-Output Symbolic Transition Systems (IOSTs). Symbolic Transition Systems (STs) are introduced by Frantzen et al. [7]. A tool that generates tests based on symbolic specification is the STG tool, introduced in Clarke et al. [3].

7.3 Graph transformations

Graph transformations have been studied since the early '70s. The usage of this computational paradigm is best described by the following quote from Andries et al. [1]: "Graphs are well-known, well-understood, and frequently used means to represent system states, complex objects, diagrams, and networks, like flowcharts, entity-relationship diagrams, Petri nets, and many more. Rules have proved to be extremely useful for describing computations by local transformations: Arithmetic, syntactic, and deduction rules are well-known examples." An informative paper on graph transformations is written by Heckel et al. [5]. A quote from this paper: "Graphs and diagrams provide a simple and powerful approach to a variety of problems that are typical to computer science in general, and software engineering in particular." These quotations support the assumptions made in section ??.

The modelling tool GROOVE has been applied to several case studies, such as model transformations and security and leader election protocols [4].

8 Conclusion

This report motivates the need of a research towards a model-based testing practice on Graph Transformation Systems. The research will investigate whether the assumption that GTSs will provide a more understandable, easier practice is true. The goal will be to create a tool that allows automatic test generation on GTSs and assess the strengths and weaknesses of this test practice.

The first results in this report demonstrate that GTSs can provide a nice overview of a system. However, also the STs are clear for this simple example. Increasing the complexity of the software system may change this. The transformation rules, given as separate graphs, provide a good overview of the *behavior* of the system. This feature should be beneficial in models for larger software systems.

The results also show an interesting automatic statespace reduction, namely the symmetry reduction. The second GTS of the example shows that also a purely arithmetic model can be built; this indicates the strength of the formalism.

The design phase is split into small steps that should break down the complexity of the entire implementation process. The validation with the use of the case studies emphasises the practicality of the tooling; the purpose of the test tools is to be used on real-world software systems. Finally, the experiments are a great indication of the usefulness of the tool towards software testers.

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A Planning

| When | What | Deliverable |
|-------------------------------|--|---|
| week 1-3 2 Jan - 22 Jan | Implementing basic interfaces for both tools. Creating SUT of boardgame example. | Working system for automatic test generation on GTSs by generating LTS. |
| week 4-6 23 Jan - 12 Feb | Setting up transformation rules for GTS-to-STS. Implementing transformation on GROOVE interface. | 1) GTS-to-STS transformation rules. 2) System for automatic test generation on GTSs by generating STS. |
| week 7-10 13 Feb - 11 Mar | Implementing GTS engine on the Axini tool and graph/rule coverage on the GROOVE tool. | System for automatic on-the-fly test generation on GTSs with coverage statistics. |
| week 11-13 12 Mar - 1 Apr | Creating GTSs for each case study. | Graph-based models of several software systems. |
| week 14 2 Apr - 8 Apr | Running the implemented system on the created models. | Measurements and comparison of both tools on objective criteria. |
| week 15-16 9 Apr - 22 Apr | Optional: Researching possibilities of data coverage + implementation. | Support for data coverage statistics in both tools. |
| week 17-19 23 Apr - 13 May | Setting up experiments with participants. | Buggy models, case descriptions, appointments for experiments. |
| week 20 14 May - 20 May | Running experiments. | Measurements and comparison of both tools on subjective criteria. |
| week 21-23 21 May - 10 Jun | Finish writing thesis. | The final thesis. |